JOINT TACTICAL RADIO SYSTEM – WAVEFORM PORTING

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ABSTRACT

An enabling concept of Joint Tactical Radio System (JTRS) to provide global connectivity to the warfighter is the development of radio waveforms and applications that can be readily ported to different members of the JTRS radio family. Waveform porting is a pragmatic realization that ubiquitous plug-and-play is not possible for tactical radios possessing different hardware architectures and missions. In this paper, a recent waveform porting activity is presented and discussed.

INTRODUCTION

JTRS Waveform porting is the re-hosting of a JTRS waveform from the Information Repository (IR) onto a radio platform. Because the different platforms in the JTRS family of radios have different hardware and software environments, some software integration activity is expected. Figure 1 illustrates a waveform on a JTR Set. The JTRS Infrastructure [1-2] is intended to isolate radio set implementations from the waveform software. In Figure 1 the isolation is provided by the Software Communications Architecture (SCA) and the JTRS Application Programming Interfaces (APIs).

The APIs and SCA in Figure 1 represent a compromise. A complete and detailed specification that facilitated plug-and-play would require substantial growth in the physical size and power requirements of the radio which would compromise radio mission success. The gap between perfect plug-and-play and the realized isolation between the waveform and the JTR Set represents the porting activity of a waveform.

An example of a porting activity or gap in plug-and-play might be the refactoring of Digital Signal Processor (DSP) code from one manufacturer's product to another manufacturer. Real-time software cannot always tolerate thick abstraction layers which could isolate the interrupt processing. The pragmatic solution is to change a few lines of code instead of enduring the latency and resource costs of a complete abstraction layer.

The business model of JTRS waveform porting is reduced cost and schedule, increased interoperability, and faster technology insertion. As a component of the JTRS Enterprise Business Model (EBM), JTRS waveforms and applications are procured with a minimum of Government Purpose Rights (GPR). The government's ownership of these intellectual property rights for the DoD enables waveforms and applications to be shared and ported across the entire JTRS product line. A common code base enhances interoperability and the time to field new capabilities.

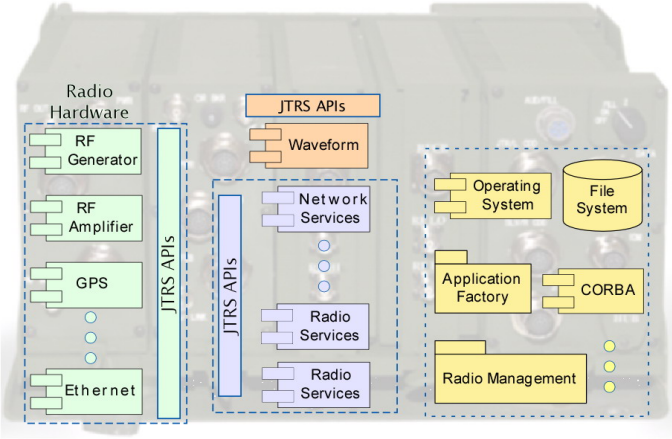

Figure 1 Waveform in a JTR Set

PORTING ACTIVITIES

Wideband Networking Waveform (WNW) is a self-forming, self-healing, wireless network that allows the Joint Services to communicate securely with each other in the tactical battlefield as well as provides access to the Global Information Grid (GIG). Figure 2 depicts how WNW supports the tactical environment.

WNW was initially developed upon a Commercial-Off-the-Shelf (COTS) representation of the JTRS Ground Mobile Radio (GMR) hardware (i.e., surrogate radio). The surrogate radio hardware emulated the major components of the pre-Early Development Model (EDM) JTRS GMR. A modem abstraction layer named Quixote Hardware Abstraction Layer (QHAL) was developed to support the initial WNW development. This abstraction layer performed the communications between the General Purpose Processors (GPPs), DSP, and Field Programmable Gate Array (FPGA). This QHAL was also supported upon a COTS modem board. A JTRS Surrogate Radio (JSR) was generated to facilitate development and testing prior to delivery of the GMR radio sets. It accurately emulates the GMR EDM radio.

After the JTRS GMR pre-EDM radio hardware became available, WNW development shifted from the surrogate radio hardware to the JTRS GMR pre-EDM radio hardware. This platform was continued through

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WNW 1.1. After WNW 1.1, there were sufficient quantities of JTRS GMR pre-EDM hardware to support development and the surrogate radio hardware was used only in a limited capacity by WNW developers. JTRS then began to redeploy the surrogate radios for testing and analysis of waveform software

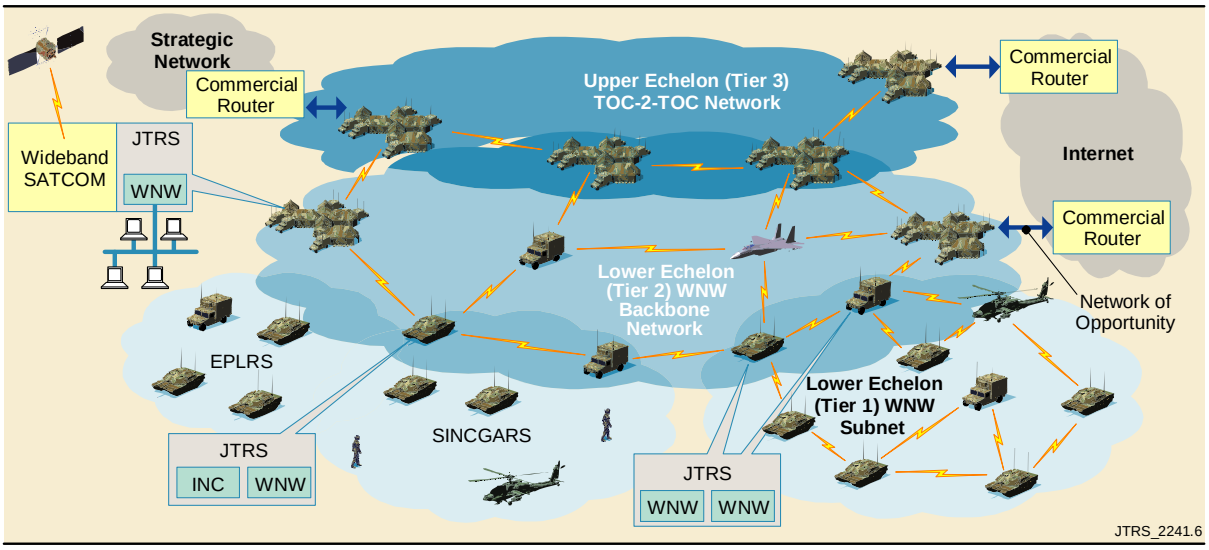

Figure 2 WNW in Tactical Environment

An early version of WNW (i.e., WNW 1.1) had been previously ported to the JSR and represented a baseline for porting WNW 2.0 to the JSR. This porting began in December 2007. The expected hardware and software minor issues with the JSR were resolved during the subsequent porting.

The primary porting strategy was to port WNW using a modular approach, similar to the development of WNW. There were three teams organized for the porting; modem, GPP, and Support Team. As illustrated in Figure 3, the modem team began porting the physical layer using Signal in Space (SiS) Test. SiS Test is a tool that provides a simplified emulation of the upper layers of WNW. This allowed porting of the physical layer while isolating the issues that existed with the porting of the upper layers. The GPP Team began porting using MDL-Lite. Mobile Data Link (MDL) Lite is a tool that provides a simplified emulation of the MDL [5] and Physical Layer. After these two activities were complete, the porting team worked on the integration of the MDL Layer. This was the final step to porting WNW 2.0 to the JSR.

These tools facilitated independent porting of the individual waveform layers. The strategy dramatically reduced the porting time and simplified problem solving by removing dependencies. Isolating a particular layer or function and analyzing that layer independently is a vital concept that reduces porting costs. The team of 7 engineers completed the WNW 2.0 port in approximately 4 calendar months with many lessons learned.

These lessons learned are being used to improve the enterprise JPEO JTRS porting process. There are also other concepts that JTRS Network Enterprise Domain (NED) is evaluating; the first is, a porting tool box. Each waveform should have a complete archive of tools that can be downloaded with the waveform. This will reduce the time it takes developers to learn, port, and test each waveform. The second is a Test API for networking waveforms. It is difficult to extract state variable information from within the waveform without impacting network performance. The JTRS NED is currently developing a test application that would facilitate viewing internal waveform information, thus improving the analysis capability during a port.

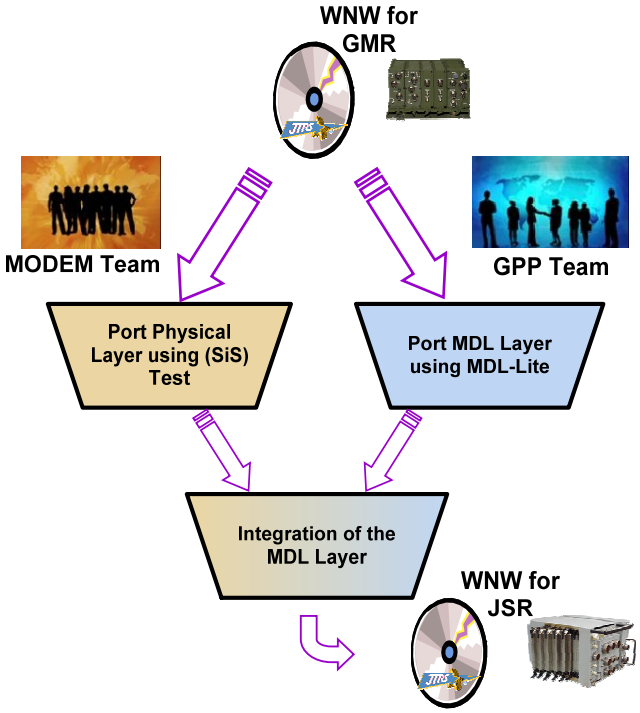

Figure 3 Porting WNW

Documentation and source code comments are critical to successful porting of any waveform. When documentation and comments were discovered inadequate, Software Anomaly Reports (SARs) were generated for the JTRS GMR prime contractor to correct the deficiencies. There were also small waveform issues that have been subsequently corrected by the developer. Examples include processor-to-processor communications, parameter interaction, and erroneous readings from the Operating Environment (OE) event analyzer.

IMPROVING WAVEFORM PORTABILITY

Figure 4 illustrates a categorization of source code for DSPs that frequently appear in waveform implementations.

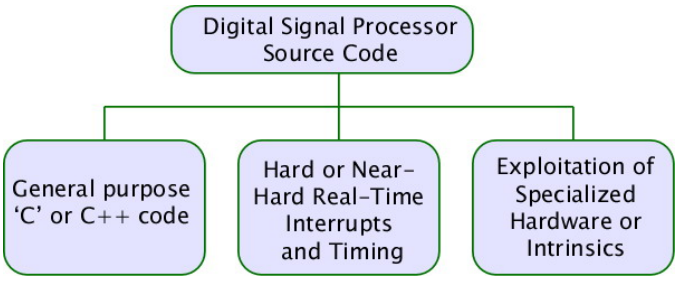

Figure 4 Categorizing Source Code for DSPs

Fortunately, substantial portions of a waveform's DSP source code are very similar to GPP source code and can be categorized as general purpose C or C++ source code. For such software, Portable Operating System Interface (POSIX)-compatible instructions are compiled into native processor instructions and little developer touch-labor is required to port this style of source code from one processor to another.

Because DSPs frequently process data with hard or nearly-hard real-time requirements, tight coupling of processing flow to interrupts or timers is required. Strategies such as hardware abstraction layers can reduce the coupling, but at the cost of increased delay and variability. This category of source code has much increased developer touch-labor in porting. System integration and regression testing can be difficult with the lack of analysis capability inside a software defined radio, hence the development of the Test API previously discussed.

The third category of DSP source code in Figure 4 is programming that deliberately exploits the intrinsic or special hardware capabilities of the signal processor. It is often specialized instructions such as a Fast Fourier transform (FFT) butterfly or Viterbi processing that distinguish signal processors from GPPs and provide substantial leaps in processing performance. Although easier to port than hard real-time interrupts and timer processing, this source code still requires substantial developer touch-labor in waveform porting. The hardware accelerator functions may need to be replaced with time-critical software modules.

To reduce the porting activity of DSP source code, the waveform must be initially developed with future porting as a design requirement. Realistic expectations of future radio architectures and pragmatic allocation between portability, processing performance, and Size, Weight and Power (SWaP) are required during waveform development.

Porting the FPGA allocations of a waveform application have been the most difficult and time consuming per source line of code. One explanation is that software programming styles and techniques for C and C++ are more mature than for Very High Speed Integrated Circuit (VHSIC) hardware description language (VHDL) and Verilog. A second factor is that most frequently, waveform processing in an FPGA has hard or near-hard real-time requirements and as discussed with DSPs, time criticality requires increased developer touch-labor in porting. Three additional considerations for FPGA porting are illustrated in Figure 5.

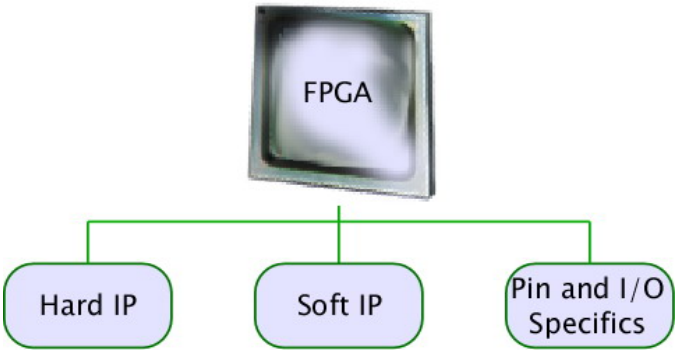

Figure 5 Considerations for FPGA Porting

Different vendors and even different product lines from a specific vendor have device-specific implementations of hard Intellectual Property (IP). These are pre-fabricated functions such as phase-locked loops, processor cores, multipliers, adders, etc. It would be possible for waveform developers to write these functions in primitive VHDL, but their performance and resource utilization would be more costly than what the FPGA vendors provide as hard IP. Because form, fit, and function are not the same between vendors or product lines, developer touch-labor can be required in waveform porting.

Soft IP are functions written in VHDL or Verilog, but typically specific to a particular FPGA chip's hard IP. As an example, a Reed Solomon decoder might be included within a waveform. Although primitive VHDL could be written to implement these functions, it requires pragmatism to balance the requirements of waveform porting, code maintenance, and development costs.

The pin count, allocation, and I/O implementations are very specific to an FPGA device. Sometimes multiplexing of I/O and interrupts may be required in waveform porting which can be very intensive in developer touch-labor.

Similar to the waveform DSP source code, the best opportunity for minimizing FPGA waveform porting occurs during waveform development. Perhaps most desirable is a bit-true high-level model such as Matlab/Simulink or System C that is delivered with the waveform, complementing the VHDL or Verilog source code. Commercial tools are being developed that can compile the high-level model and reduce the developer touch-labor associated with the FPGA porting.

OUTREACH INITIATIVES

JPEO JTRS has initiated several activities to improve waveform porting. The Calit2/JTRS Software-Defined Radio Project, a joint research effort of the University of California, San Diego (UCSD) division of the California Institute for Telecommunications and Information Technology (Calit2), the JPEO and SPAWAR Systems Center, Pacific (SSC-P) was established to bridge government, commercial and academic innovation geared towards JTRS. Calit2 has been tasked by JPEO JTRS to port the Future Multiband Multiwaveform Modular Tactical Radio (FM3TR) waveform and study the porting process.

In addition, the DoD Small Business Innovation Research (SBIR) program is supporting innovation in waveform porting and software radio architectures and infrastructures. Several executing Phase I and Phase II projects are generating new ideas and concepts for waveform porting. The Navy has also funded innovation initiatives through SPAWAR Systems Center Charleston for porting the WNW waveform.

Cooperative Research and Development Agreements (CRADAs) have been established between the Navy/JTRS and commercial vendors to study waveform porting and provide recommendations to the government.

As illustrated in Figure 6, the software defined radio architecture permits software-only changes to introduce new functionalities and mission capabilities. These software additions will benefit from improved waveform porting processes.

ICWG ESTABLISHMENT

The JPEO recognized the need to define a complete and common host environment early in its inception. In 2005 the JPEO created the JTRS Standards Interface Control Working Group (ICWG) to define a set of JTRS specifications and standards that promote waveform portability. The baseline specifications and standards include the Software Communication Architecture (SCA) [3-4] and key system interfaces that provide waveform-to-JTR set communication (i.e. APIs). The ICWG also to maintains, manages, and evolves these standards and specifications as new technology and missions emerge.

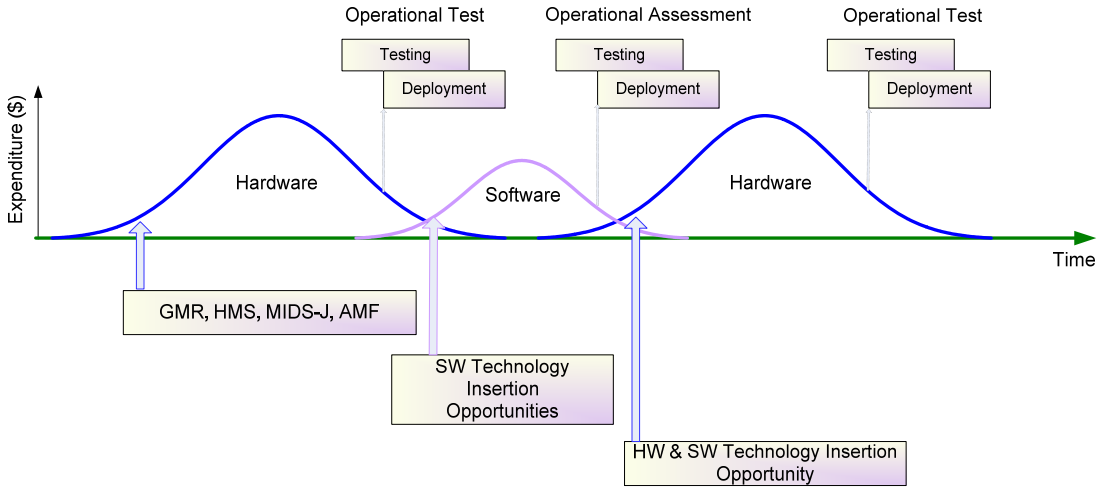

Figure 6 Technology Insertion Opportunities

The JTRS Standards ICWG serves as the technical and decision-making authority to the JPEO JTRS Configuration Control Board (CCB) for the development and configuration management over all JTRS Standards. The ICWG membership includes representatives across the JTRS Enterprise. As shown in Figure 7, the ICWG organization is comprised of an ICWG Chair, its Board members, and a support staff. Currently the ICWG has over 300 active members including representatives from the program offices and developers from all the JTR sets and NED, representing all the waveforms as well as Mobile User Objective System (MUOS), F/A 22, NSA, NASA and DARPA.

The JPEO has modeled the ICWG charter and standardization process after other international standardization processes. The ICWG Chair conducts JTRS Standards conferences on an as required basis for the disposition of JTRS Standard Change Proposals, as well as other issues related to the JTRS Standards Configuration Management. The ICWG Chair and members of the ICWG Board are allowed one vote per issue brought before the ICWG.

In creating the initial JTRS infrastructure definition the ICWG acknowledged that there were several million existing Lines of Code (LOC) in the JPEO Information Repository (IR) which the JTRS enterprise needed to be backwards compatible as well as needing to be extensible and scalable to the various form factors and missions that were still in development. The JTRS ICWG began with the legacy GMR APIs and retained pieces that would ease waveform portability and could be applied across the JTRS Enterprise.

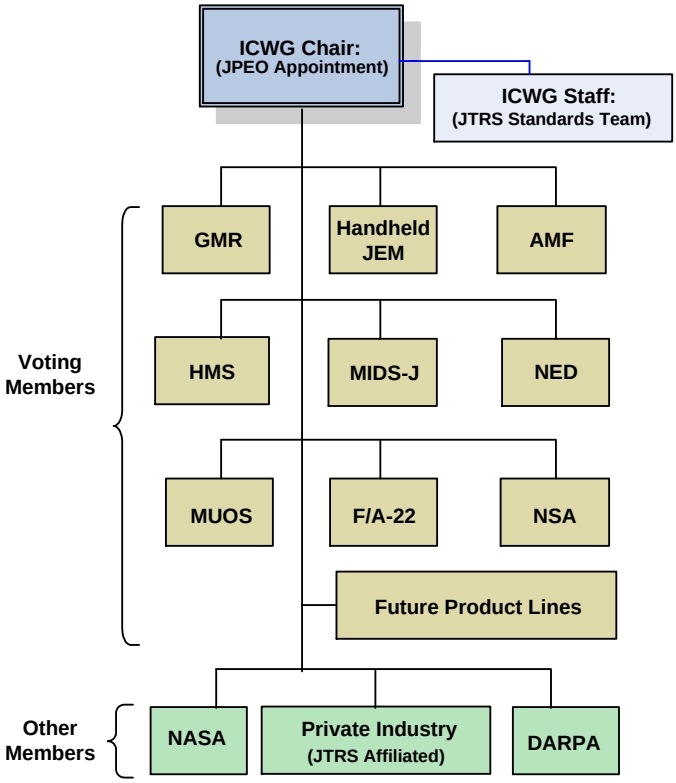

Figure 7 JTRS ICWG

This approach promotes reuse by defining consistent interfaces and standards across the JTRS radio family. The JTRS infrastructure allows for faster product development, new capability fielding, interoperability, reduced software maintenance, and enterprise-wide documentation. Reuse and portability of JTRS waveform and applications hosted on DoD radios and terminals is dependent upon the proper specification of a standardized architecture.

PORTABILITY GUIDELINES

In an effort to improve the portability of JTRS waveforms, the Government, working with representatives from various groups in industry, has developed a set of Waveform Portability Guidelines (WPG). These guidelines provide guidance to multiple participants in the waveform acquisition programs. First, the WPG provides the Government acquisition team with guidance on what to require from the waveform developer. Second, the Government test and evaluation team uses the WPG as the criteria for evaluating the waveform. Finally, the WPG provides the waveform developer with guidance on the design, development, and documentation practices that maximize waveform portability.

The WPG guidelines are a compilation of information from various sources including:

- Lessons learned from Government porting efforts
- Engineering teams within the JTRS program
- Other Government Software Defined Radio (SDR) programs
- Waveform and radio developers
- Tool developers and component manufacturers
- Respected experts in the SDR community
- Known hardware designs

The goal of the WPG is to improve portability within the context of the JTRS program. Many of the practices required by the WPG are applicable to any embedded software application that requires portability, and can have a wider use beyond the boundaries of the JTRS program. The WPG serves as a common definition of waveform portability that ensures that both the Government and the developer agree on expectations and requirements. As a cooperative effort between Government and industry, the WPG points the way for future DoD technology development.

The WPG is written from the perspective that the end product of JTRS waveform development is not a binary software application. Instead, the end product is a set of source files that, with minimal changes, can be compiled and linked into a waveform capable of being hosted on a number of different platforms, along with the supporting documentation necessary to enable a third-party to port and optimize the waveform for a specified platform.

The WPG provides the waveform developer with guidance on the design, development, and documentation practices that maximize waveform portability. The WPG documents general waveform design guidelines including:

- Consideration of the intended use of the waveform
- Use of third-party software
- Development tools and debug code
- Modeling
- Waveform architecture
- Inline documentation

The WPG also provides waveform programming and development guidance for developing code for GPPs, DSPs, and FPGAs processor types. The WPG provides documentation guidelines to ensure everything necessary to recreate the design and its motivation is available without the need to consult the waveform designer.

The Government will periodically update the WPG to include new insight gained from continuing development and porting efforts by both Government and industry. Along with improving the depth and breadth of information, this will serve to keep the guidelines current with the latest tools and techniques available.

SUMMARY

JTRS has proven experience with applying the lessons learned and new techniques in the recent WNW porting activities. Although complete plug-and-play is not practical for waveform porting, the JTRS objective of minimizing a waveform's software adaptation delta has many applications outside of JTRS. The JTRS approach of waveform and application portability enables global connectivity to the warfighter by addressing, mitigating, resolving the associated risks and challenges surrounding waveform porting.

REFERENCES

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BIOGRAPHIES

Donald R. Stephens, PhD is the JPEO JTRS Standards Manager. He has development experience with Digital Modular Radio (DMR), the Joint Tactical Terminal (JTT), and the Airborne Integrated Terminal Group (AITG). He has extensive experience in multiple communications and radar receiver systems with companies such as Raytheon E-Systems, McDonnell Douglas, Emerson Electric, and Scientific Atlanta.

Richard Anderson is a Senior Engineer at SSC, Charleston. He has served as the JTRS NED T&E Program Manager since January 2007. Before that, he was the NED T&E Chief Engineer. He has a Bachelor of Science degree in Electrical Engineering from The Citadel and a Master of Engineering Degree from Clemson University. His work includes supporting the development of JTRS representative hardware used in testing and assessment of JTRS waveforms, JTRS Waveform porting, lead engineer for developing Portability Guidelines and Assessment Procedures.

Chalena M. Jimenez is a Senior Systems Engineer for Celerity, Inc. supporting the JPEO JTRS Standards team. Mrs. Jimenez has worked integrally with the JTRS community to establish baseline specifications and standards for the JTRS enterprise. Mrs. Jimenez has developed SDR components for the Joint Strike Fighter (JSF). Prior to her work on JSF she worked as a computer scientist at SSC, San Diego developing a JTRS SDR prototype. Mrs. Jimenez earned a B.S. in Computer Science cum laude from the University of California, San Diego.

H. Lane Anderson, NED T&E – SPAWAR System Center Charleston, is the NED T&E Portability Lead, and a Principal Engineer with Scientific Research Corporation. He is the primary author of the WPG and the Waveform Portability Assessment Procedures (WPAP). He has 30 years of experience in software development, architecture, and management, including extensive experience in development of satellite communications protocols and system infrastructure software for the commercial telecommunications industry.